Frequently Asked Questions about the Hydromodification Management Criteria

1. What is Hydromodification?
2. Why should I be concerned about hydromodification?
3. What is hydromodification management?
4. How do I know if the hydromodification requirements apply to my project?
5. What if my project is located EAST of the Pacific/Salton divide, therefore outside of the jurisdiction of the San Diego Regional Water Quality Control Board?
6. How do I know if my project, which is currently in the plan review process, needs to meet the Interim Hydromodification Criteria or the Final Hydromodification Criteria?
7. What is a geomorphic assessment and how do I perform one?
8. How do I perform a continuous simulation model?
9. How can I show that my project, which is a priority development project, is exempt?
10. Where can I find additional County of San Diego guidance regarding compliance?

1. What is Hydromodification?

- The change in the natural hydrologic processes and runoff characteristics (i.e. interception, infiltration, overland flow, interflow and groundwater flow) caused by urbanization or other land use changes that result in increased stream flows and changes in sediment transport. In addition, alteration of stream and river channels, installation of dams and water impoundments, and excessive streambank and shoreline erosion are also considered hydromodification, due to their disruption of natural watershed hydrologic processes. The extent of hydromodification can be quantified by observing the change of the flow-duration curve (representing the change in discharge over time) for a given section from an initial condition to one that results from human-influenced modifications in the watershed.

2. Why should I be concerned about hydromodification?

- Hydromodification is one of the leading sources of impairment in streams, lakes, estuaries, aquifers, and other waterbodies in the United States. Hydromodification not only changes a waterbody's physical structure, it also changes its natural function. These changes can cause problems such as changes in flow, increased sedimentation or erosion, higher water temperature, lower dissolved oxygen, degradation of aquatic habitat structure, loss of fish and other aquatic populations, and decreased water quality. It is important to properly manage hydromodification activities to reduce nonpoint source pollution in surface and ground water and to ensure the effectiveness of the municipal storm sewer system.

3. What is hydromodification management?

- It is the management of post-project runoff flows and durations so that they are maintained to the levels of the pre-project condition. More specifically, to manage runoff such that development in the watershed does not increase the flow-duration curve by more than a given percentage for a specified range of significant flows.

4. *How do I know if the hydromodification requirements apply to my project?*
   - If your project is a priority development project, it must manage hydromodification impacts, or show that it is exempt. A project is a priority development project if it is WEST of the Pacific/Salton Divide and has a yes answer to any of the questions in the following table. Also, please refer to the HMP Applicability Determination Decision Matrix (Figure 6-1 of Final HMP on following page.) for more detailed guidance on navigating the procedure.

Is the project in any of these categories?

Yes ❑	No ❑	**A**	**Housing subdivisions of 10 or more dwelling units.** Examples: single-family homes, multi-family homes, condominiums, and apartments.
Yes ❑	No ❑	**B**	**Commercial—greater than one acre.** Any development other than heavy industry or residential. Examples: hospitals; laboratories and other medical facilities; educational institutions; recreational facilities; municipal facilities; commercial nurseries; multi-apartment buildings; car wash facilities; mini-malls and other business complexes; shopping malls; hotels; office buildings; public warehouses; automotive dealerships; airfields; and other light industrial facilities.
Yes ❑	No ❑	**C**	**Heavy industry—greater than one acre.** Examples: manufacturing plants, food processing plants, metal working facilities, printing plants, and fleet storage areas (bus, truck, etc.).
Yes ❑	No ❑	**D**	**Automotive repair shops.** A facility categorized in any one of Standard Industrial Classification (SIC) codes 5013, 5014, 5541, 7532-7534, or 7536-7539.
Yes ❑	No ❑	**E**	**Restaurants.** Any facility that sells prepared foods and drinks for consumption, including stationary lunch counters and refreshment stands selling prepared foods and drinks for immediate consumption (SIC code 5812), where the land area for development is greater than 5,000 square feet. Restaurants where land development is less than 5,000 square feet shall meet all SUSMP requirements except for structural treatment BMP and numeric sizing criteria requirements and hydromodification requirements.
Yes ❑	No ❑	**F**	**Hillside development greater than 5,000 square feet.** Any development that creates 5,000 square feet of impervious surface which is located in an area with known erosive soil conditions, where the development will grade on any natural slope that is twenty-five percent or greater.
Yes ❑	No ❑	**G**	**Environmentally Sensitive Areas (ESAs).** All development located within or directly adjacent to or discharging directly to an ESA (where discharges from the development or redevelopment will enter receiving waters within the ESA), which either creates 2,500 square feet of impervious surface on a proposed project site or increases the area of imperviousness of a proposed project site to 10% or more of its naturally occurring condition. "Directly adjacent" means situated within 200 feet of the ESA. "Discharging directly to" means outflow from a drainage conveyance system that is composed entirely of flows from the subject development or redevelopment site, and not commingled with flows from adjacent lands.
Yes ❑	No ❑	**H**	**Parking lots 5,000 square feet or more** or with 15 or more parking spaces and potentially exposed to urban runoff.
Yes ❑	No ❑	**I**	**Street, roads, highways, and freeways.** Any paved surface that is 5,000 square feet or greater used for the transportation of automobiles, trucks, motorcycles, and other vehicles.
Yes ❑	No ❑	**J**	**Retail Gasoline Outlets (RGOs)** that are: (a) 5,000 square feet or more or (b) a projected Average Daily Traffic (ADT) of 100 or more vehicles per day.

This table can be found on SUSMP Page 5, Table 1-1, the Stormwater Intake Form, and both Major and Minor SWMP Forms.

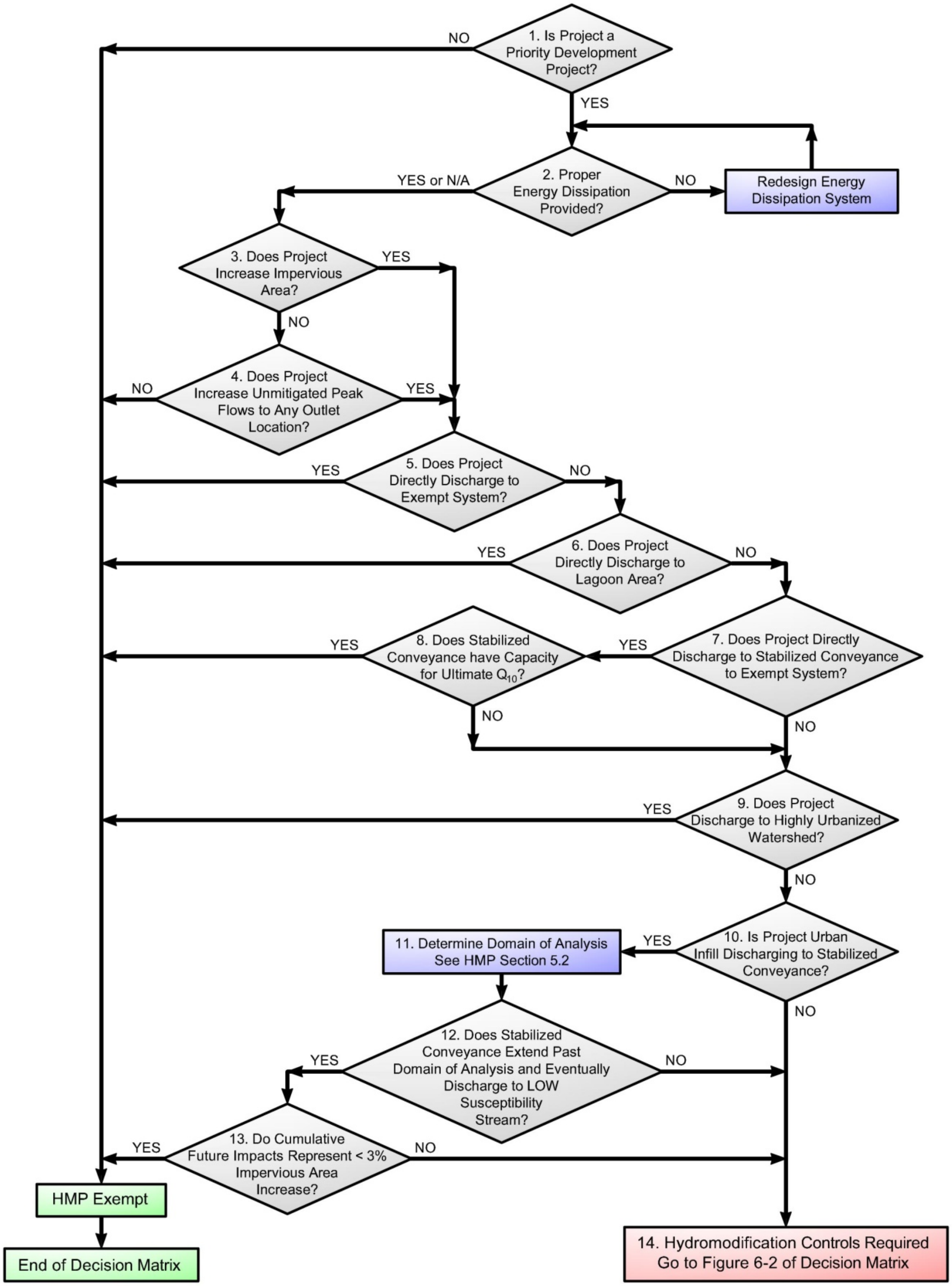

Figure 6-1. HMP Applicability Determination (Figure 6-2 at end of this document)

5. *What if my project is located EAST of the Pacific/Salton divide, therefore outside of the jurisdiction of the San Diego Regional Water Quality Control Board?*
   a. Projects east of the Pacific/Salton divide are out of the jurisdiction of the San Diego Regional Board and its NPDES Permit. Therefore, those projects which disturb one or more acres are subject to the California State Construction General Permit Hydromodification requirements, per San Diego County DLI-LD-R, dated September 15,2010, which states:

      "Priority Development Projects located to the west of the Pacific/Salton Divide shall follow the hydromodification management methodology described in the County's Standard Urban Storm Water Mitigation Plan (SUSMP), per the Regional Stormwater Permit. Projects with construction sites that disturb one or more acres of land surface located to the east of the divide shall follow the hydromodification management methodology described in the State General Construction Permit"

6. *How do I know if my project, which is currently in the plan review process, needs to meet the Interim Hydromodification Criteria or the Final Hydromodification Criteria?*
   - Please verify with your County DPW project manager who will confirm with County Counsel. Generally, if your project does not have a prior lawful approval, it will have to meet the final hydromodification management criteria. The Final Criteria go into full effect by January 14, 2011 at which point all projects will be subject to the Final Hydromodification Criteria.

7. *What is a geomorphic assessment and how do I perform one?*
   - If your project follows the interim criteria, review the PWA memo, dated May 14, 2008 at the following link. It is only valid until January 14, 2011 when the final criteria go into effect.
     http://www.projectcleanwater.org/pdf/susmp/hydromod_geomorphic_assesment_may_08.pdf
     If your project is subject to the final criteria, please refer to the Mitigation Criteria and Implementation and SCCWRP Screening Decision Matrices (Figures 6-2 to 6-5 of Final HMP at end of this document) for more detailed guidance on navigating the procedure.

8. *How do I perform a continuous simulation model?*
   - If your project follows the interim criteria, review the B&C memo in Appendix E of the Final HMP at the following link. It is only valid until January 14, 2011 when the final criteria go into effect. http://www.projectcleanwater.org/pdf/susmp/hmp_final_12-29-09_clean.pdf
     If your project is subject to the final criteria, please refer to the Mitigation Criteria and Implementation and SCCWRP Screening Decision Matrices (Figures 6-2 to 6-5 of Final HMP at end of this document) for more detailed guidance on navigating the procedure.

9. *How can I show that my project, which is a priority development project, is exempt?*
   - You can show your project is exempt if it meets any of the following criteria:
     1. The proposed project would discharge into channels that are concrete-lined or significantly hardened, such as with riprap or sackcrete, down to their outfall in bays or the ocean;
     2. The proposed project does not increase the impervious area or peak flows to any discharge location;
     3. The proposed project would discharge into underground storm drains discharging directly to bays or the ocean;
     4. The proposed project would discharge to a channel where the watershed areas below the project's discharge points are highly urbanized (more than 70% impervious);
     5. The project is an urban infill project that discharges to an existing hardened or rehabilitated conveyance system that extends beyond the "domain of analysis" and the potential for cumulative impacts in the watershed are low.

10. *Where can I find additional County of San Diego guidance regarding compliance?*
    - What are the current Minimal Submittal requirements for an HMP? See http://www.projectcleanwater.org/pdf/susmp/hydromod_min_submittal_requirements2.pdf
    - Where can I find additional information regarding HMP? http://www.projectcleanwater.org/html/wg_susmp.html

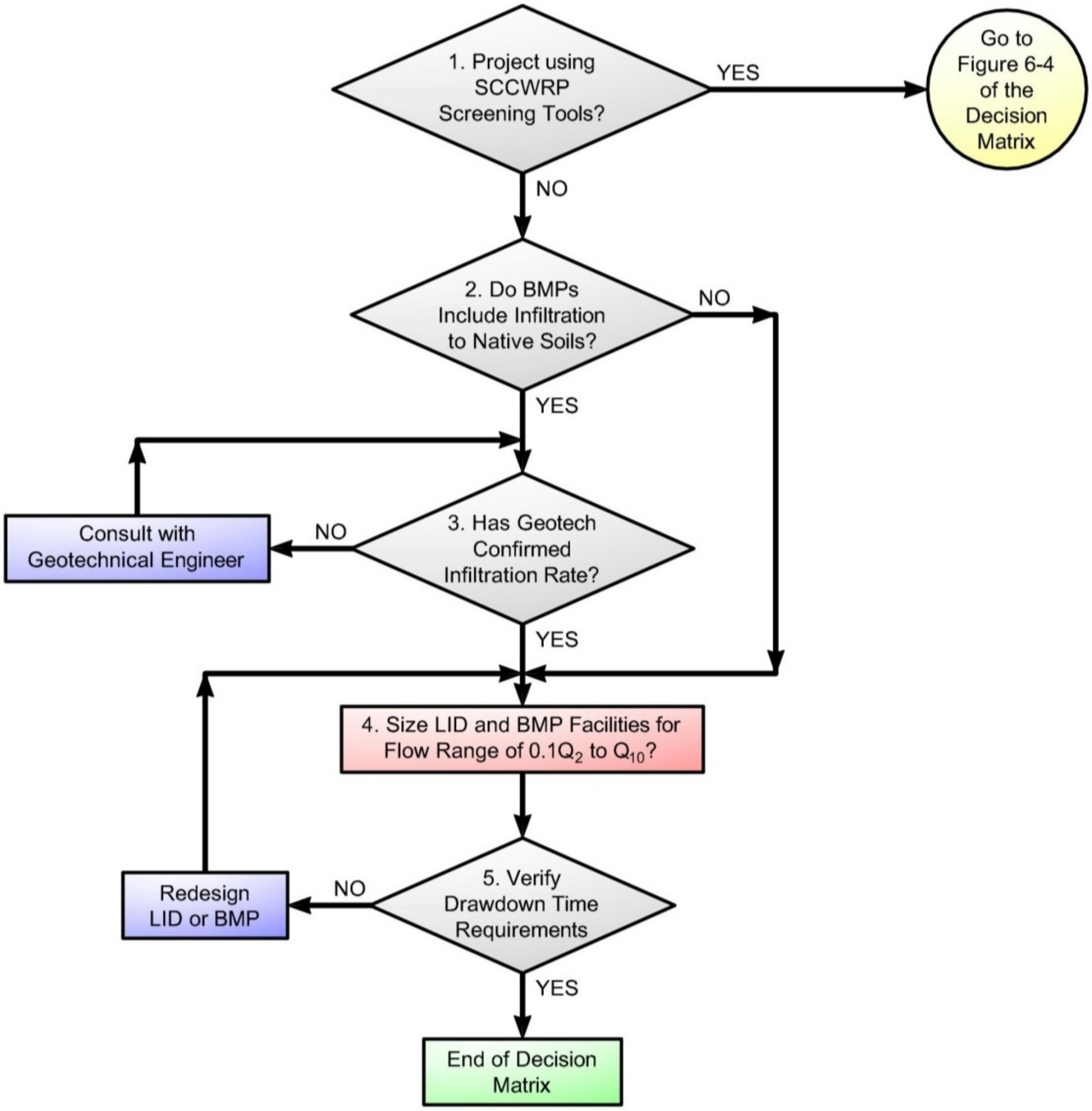

Figure 6-2. Mitigation Criteria and Implementation

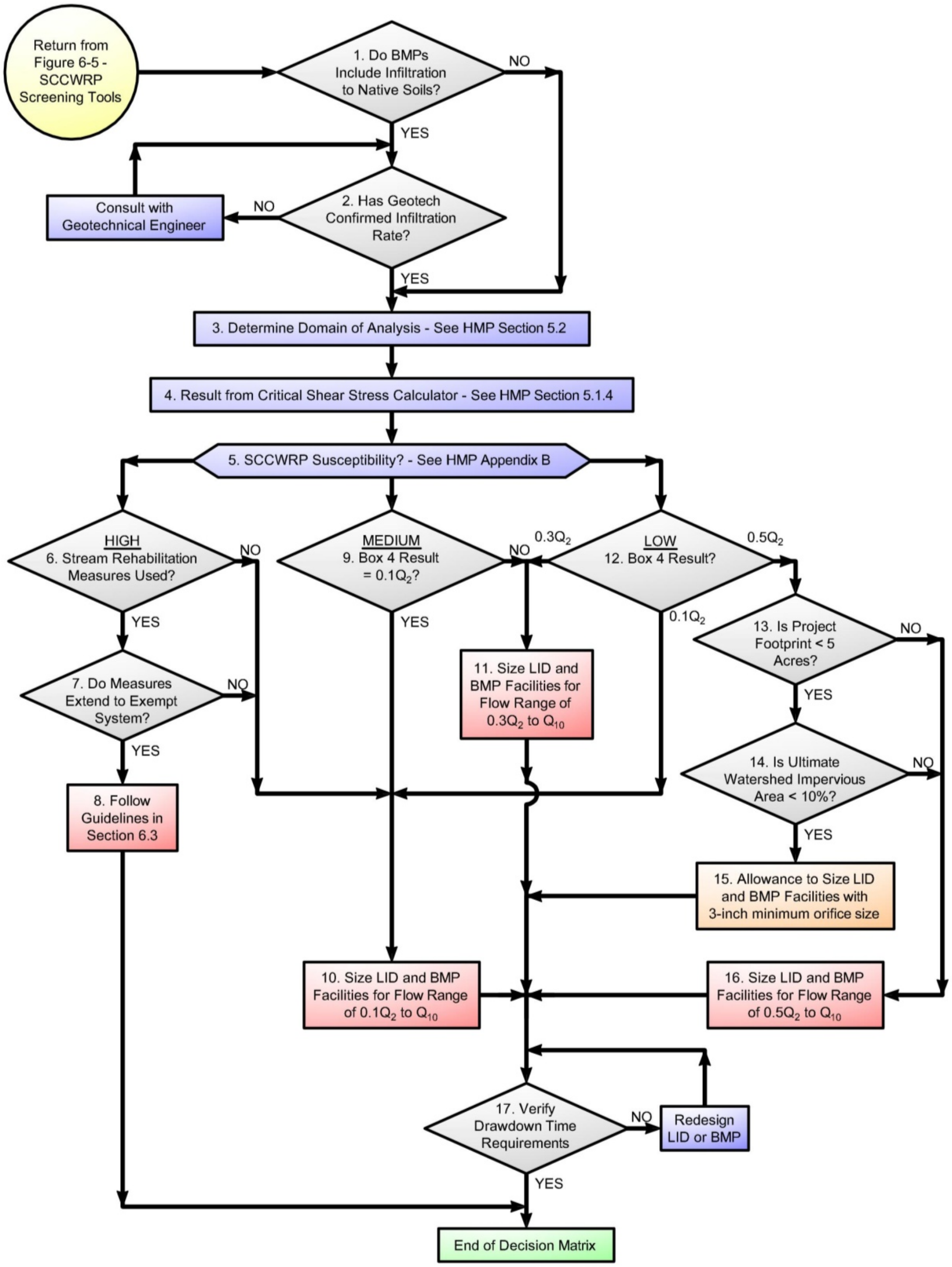

Figure 6-3. Mitigation Criteria and Implementation

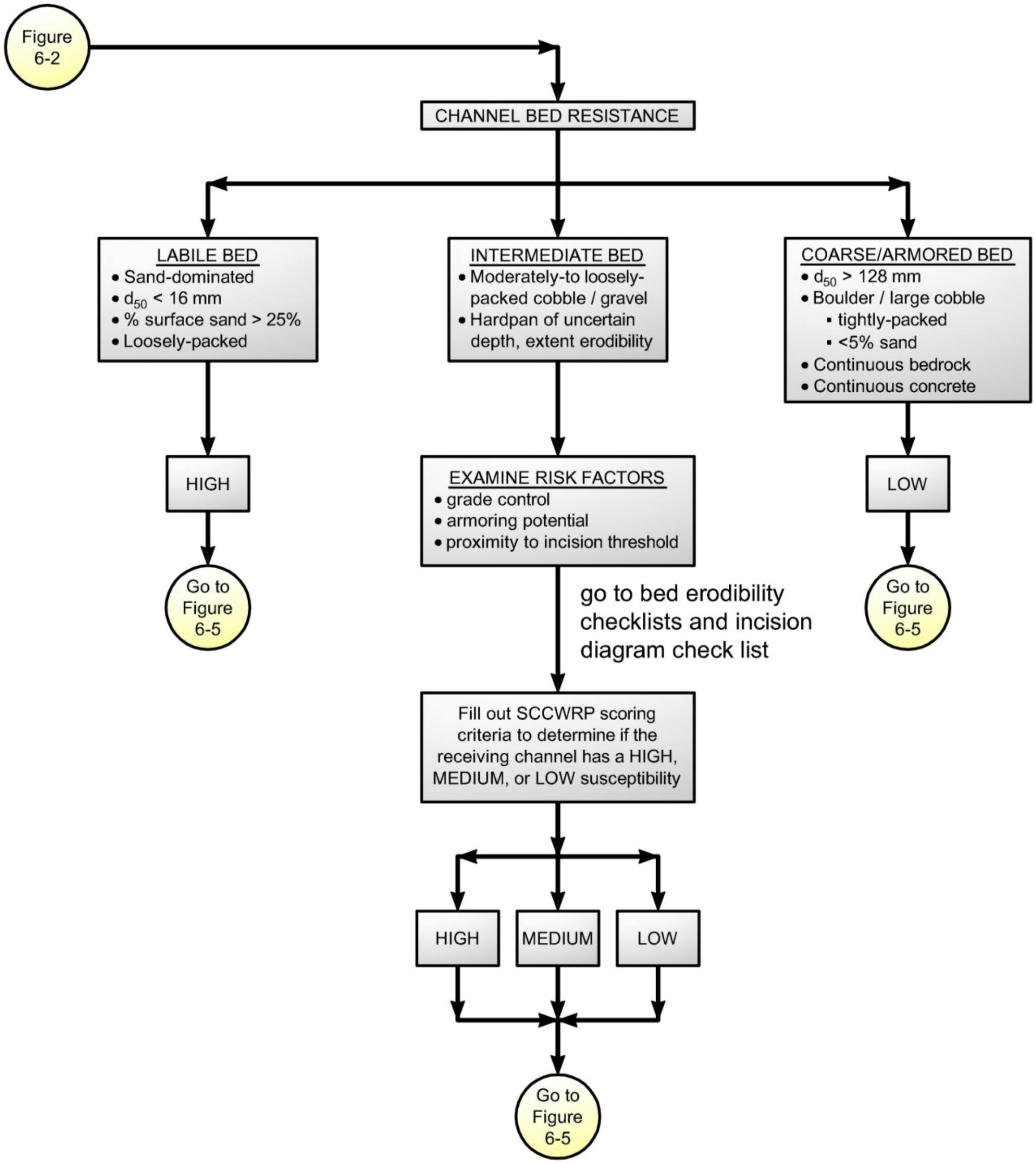

Figure 6-4. SCCWRP Vertical Susceptibility

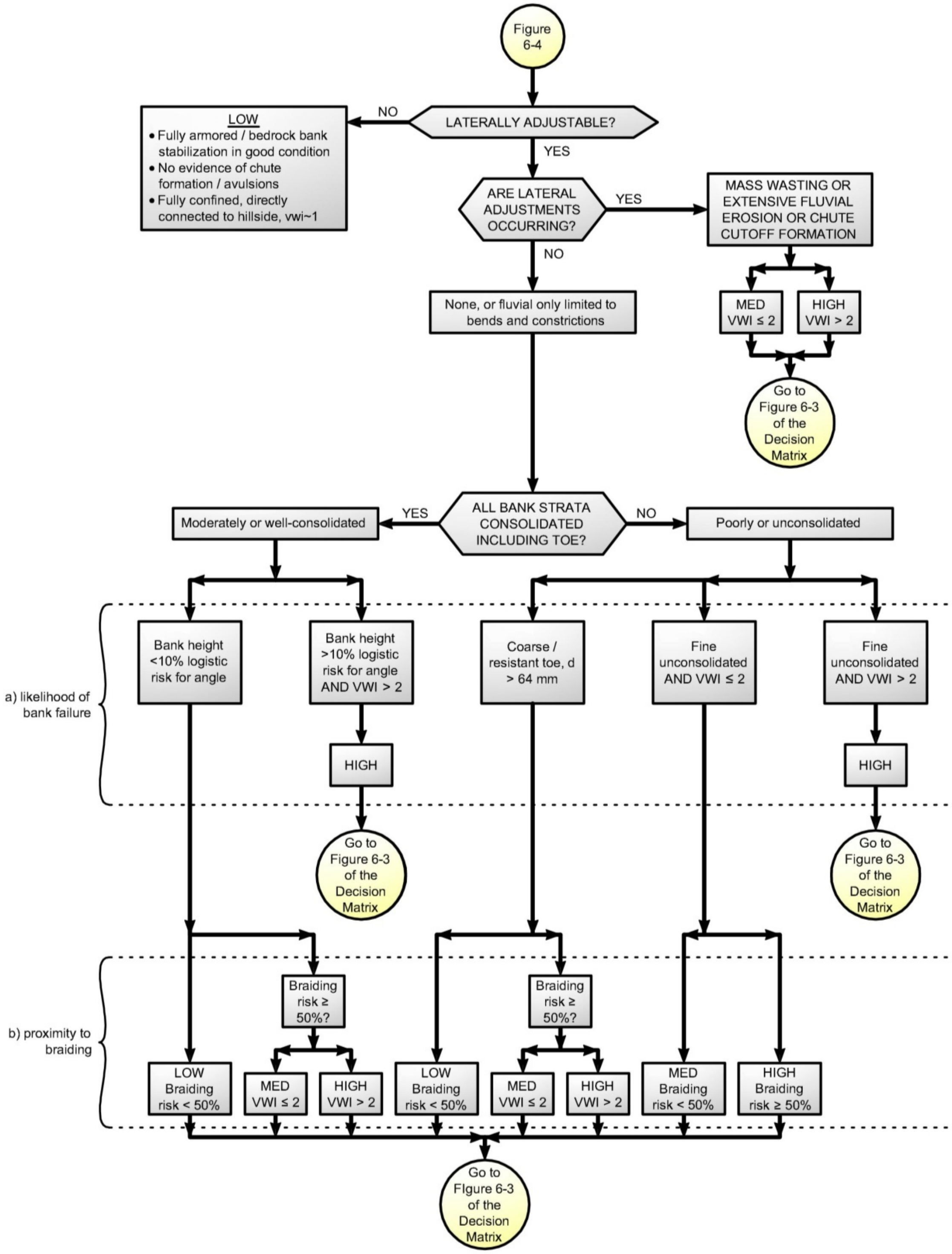

Figure 6-5. Lateral Channel Susceptibility

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MEMORANDUM

Date:	May 15, 2008
To:	Sara Agahi
Organization:	San Diego County
From:	Andy Collison
PWA Project #:	1915
PWA Project Name:	San Diego HMP
Subject:	Geomorphic analysis for interim Hydrograph Modification Plan (HMP)
Copy(ies) To:	File, Nancy Gardner

Purpose of this memo

The Interim HMP standard (February 2008) describes different options for applicants to prevent channel erosion as a result of increased runoff from developed sites. In addition to interim flow control standards and the option to use Low Impact Development (LID), there is a provision for applicants to carry out their own geomorphic assessment to demonstrate that the project will not cause erosion in the receiving water. This memo describes why an applicant might perform a geomorphic assessment and what such an assessment would typically involve.

Definitions of terms

Q5 – flow that recurs on average once every five years in the receiving water at the point of compliance.
0.2Q5 – 20% of the 5-year flow.
Q10 – flow that recurs on average once every ten years.
Bankfull flood – discharge that fully occupies the main scoured section of the creek channel (to top of bank for a non incised channel). In San Diego the bankfull flood is approximately the 5-year flow (Q5) under pre-development conditions.
Beneficial uses – uses designated by the RWQCB as beneficial for a given water body. Uses may include habitat, recreation, water supply etc.
Boundary shear stress – the erosive energy imparted by flowing water on the channel bed and banks.
Critical shear stress – the erosive energy above which flowing water causes sediment to start to erode from a creek bed or banks. Varies with particle size and cohesion.
Channel-forming flow(s) – the flow or range of flows that cumulatively transport the majority of sediment in a channel over a long period of time, and so control the size (cross sectional area) of the channel through erosion and deposition (also referred to as geomorphically-significant flows, or effective flows).
Downstream limit of influence – the point below which no significant effects of a development can be detected in the receiving channel. This can be due to one of three conditions (or a combination of all

three): channel becomes hardened all the way from this point to the ocean; channel becomes depositional from this point to the ocean, channel is joined by tributaries or is a tributary to another channel, where the cumulative flow of the combined channel is great enough that the project does not significantly alter the pre-project condition.

Flow control – measures involving enhanced infiltration or surface water detention that prevent runoff from leaving a developed site at an excessively high rate. For example, the interim flow control standard for the San Diego County HMP states that flows between 0.2Q5 and Q10 must be kept within 10% of pre-development flows over 10% of the flow duration curve.

Receiving channel – the pre-existing creek channel into which the project runoff is discharged

Background

The ultimate objective of the HMP is to prevent erosion in stream channels that receive runoff from developments. Erosion occurs because following development small to medium size flows become larger and more frequent, and receiving channels enlarge their cross sections through bed and bank erosion to accommodate the higher flows. In addition, sediment reduction from landscaping and detention basins creates 'hungry water' which has a greater sediment capacity than the same volume of sediment-laden water. Channel erosion has impacts on the beneficial uses of the water body both at the receiving site, and downstream where excess sediment is ultimately deposited. HMPs seek to prevent erosion primarily by making the pre- and post-development runoff characteristics (flow duration and peak) match within the range of flows that are responsible for most erosion (sometimes referred to as the channel-forming, or effective, flows). Numerous studies have shown that this flow range lies approximately between a value less than the bankfull flood and a value around the 10-year flood. For the Interim HMP they have been set to 0.2Q5 and Q10, and these values are being examined for the final HMP. Flows below this range generally erode and transport little or no sediment, while flows above this range are so infrequent as to have little cumulative effect.

Whilst flow control (either through the use of LID or detention facilities) is seen as the primary means of preventing erosion, and the application of simple flow control standards or LID sizing factors is seen as the most efficient way of achieving control, the Interim HMP provides some exemptions, and also allows an applicant to perform their own geomorphic analyses. The relevant section in the Interim Standard states that an exemption may be granted if "the applicant conducts an assessment incorporating sediment transport modeling across the range of geomorphically-significant flows that demonstrates to the permitting agencies satisfaction that the project flows and sediment reductions will not detrimentally affect the receiving water." There are also exemptions for hardened channels and depositional channels.

The purpose of a geomorphic assessment would be to demonstrate that a proposed project could discharge into a receiving channel in a manner that did not meet the flow control standard, but that would not cause erosion in the receiving water that exceeded pre-existing levels (within an agreed upon tolerance). This scenario may be possible for several reasons:

1. The flow control and LID standards in the HMP are average-to-conservative values, designed to simplify the application process for small projects and reduce the burden of analysis while still protecting creeks. Because rainfall, soils, topography and the nature of the receiving waters vary across the County there will be situations where less conservative flow controls or LID sizing factors will achieve creek protection.
2. The receiving channel may be depositional, so that increased flows from a project would simply bring the channel closer to sediment equilibrium.
3. In a large scale development it may be possible to configure the site's stormwater management system so that channel impacts are avoided with the use of slightly different flow controls than those put forwards in the Interim HMP (e.g. by de-synchronizing peak flows from different sub-watersheds).
4. The project may discharge into a flood channel that is so oversized that the flows would not be effective in causing erosion.

Because the potential sites and circumstances are variable, and the scale of the proposed developments varies, there is no standard prescriptive method of conducting such a geomorphic assessment. However, in this memo we lay out the required end products to demonstrate compliance and an example assessment of each of the most likely scenarios.

Geomorphic assessment examples

Conditions for all geomorphic assessments
Whatever the circumstance, the geomorphic assessment must demonstrate that increased erosion will not occur after a site is developed. It must address the range of flows that is believed to be responsible for erosion (identified in the interim HMP as 0.2Q5 to Q10).

Full runoff and sediment transport modeling of proposed site
An applicant could develop a full sediment transport model of the receiving water from the discharge point to the downstream limit and conduct continuous simulation modeling to demonstrate that the project would not cause impacts to the stream, or that the proposed flow control standards are unnecessarily conservative for their development for site specific reasons. This would involve the following steps:

Step 1. Develop pre- and post-project rainfall runoff models and conduct continuous simulation modeling. (See companion memo Brown & Caldwell, 2008, on continuous rainfall-runoff modeling.) The modeling could take place using models including HEC-HMS, HSPF (or the HSPF-derived San Diego County Hydrology Model), or SWMM. A period of at least 30 years should be simulated using local rainfall records. The model timesteps should be sufficient to capture the peak flow from small events (annual or more frequent). For small watersheds (less than 5 square miles) this is likely to require hourly timesteps during rainfalls greater than one quarter inch total.

Step 2. Run pre- and post-development flows through a sediment transport model.
The flow records from Step 1 should be routed through a hydraulic-sediment transport model of the receiving channel to the downstream limit. Applicable models include HEC-RAS version 4 and higher, HEC-6, FLUVIAL 12, and MIKE-11. The resulting channel erosion from the pre- and post-development conditions should be compared.

Applicant believes the channel is more resistant than average, and that some flows within the control range will not cause erosion.
The lower flow threshold value (0.2Q5) is actually a surrogate for *critical shear stress*, which can be hard to measure in the field and varies from site to site. If the actual critical shear stress in the receiving channel is higher than the level assumed by the flow standard there would not be a rationale for controlling flows below this level. This could occur because the channel was formed in stiff clay, or had coarse gravel or cobble bed and banks. Therefore, an applicant could legitimately try to establish whether the critical shear stress of the receiving channel was higher than the boundary shear stress at 0.2Q5, and if successful raise the level for their project to the flow at this stress level. This condition would have to be met for the channel from the discharge point all the way to the downstream limit of influence.

Potential assessment method
Step 1. Identify the critical shear stress for the receiving water.
For sandy or coarser sediments this can be calculated from the median particle size and the Shields number:

$$\tau_c = \tau^*_c\,(\gamma_s - \gamma)d_{50}$$

where

τ_c = critical shear stress (Newtons per meter squared)

τ^*_c = dimensionless critical shear stress (Shields parameter – assumed to be 0.03)
γ_s = specific weight of sediment (2.65 times water)
γ = specific weight of water (9,807 N/m3)
d_{50} = median particle size (meters)
(Critical shear stress is converted to pounds by multiplying by 0.02088)

For cohesive stream banks or beds there is no simple empirical relationship that can be used, and direct measurements are required. Critical shear stress for cohesive beds and banks can be measured in the field using a jet test (see Hansen and Cook, 2004). Alternatively undisturbed cores can be removed and testing in laboratory flumes. There are values in the literature associated with soil types, so potentially the soil types in the channel could be mapped and use made of these literature values. Whichever method was used a statistically-significant number of tests would have to be performed to characterize the channel between the discharge point and the downstream boundary (e.g. points at 20-30 locations between the discharge point and the downstream boundary).

Step 2. Identify flow associated with critical shear stress
The discharge above which erosion occurs would be identified using hydraulic modeling of the receiving water. In medium to large developments this could be achieved most efficiently by developing a hydraulic model (e.g. HEC-RAS) of the creek and for each sampled location of critical shear stress identifying the corresponding flow that generates that boundary stress. Alternatively, for a small development, it would be appropriate to develop a spreadsheet model (Excel) of flow to calculate the average boundary shear stress at a series of flows and develop a rating curve.

Step 3. Identify recurrence interval associated with the critical flow
Recurrence interval for that flow could be calculated using the methods outlined in the San Diego County Flood Manual. If the flow associated with the critical shear stress is greater than 0.2Q5 the permitees could raise the flow control standard to the actual value for critical shear stress, reducing the amount of infiltration or detention capacity needed on site to meet the HMP criteria.

Channel may be depositional
If the channel is depositional from the discharge point to the downstream limit of influence then a slight increase in flow erosivity could have beneficial effects (move sediment to the ocean rather than have deposition in a channel). This condition is likely to occur on low gradient sites (flatter than 0.5% channel gradient) relatively close to the ocean.

The assessment could either develop a sediment transport model to show that the reach was depositional, or could use direct evidence. This could include using records to show that sediment was accumulating in the channel (county sediment removal records, photographic evidence, repeat channel cross sections, CALTRANS bridge resurveys etc). Due to the episodic nature of erosion and deposition in Southern California channels it is important that long term evidence be provided. For large increases in runoff and/or where the channel is only slightly aggradational the applicant must show that the project will not tip the channel into an erosive condition, using sediment transport modeling.

Channel may be oversized
If the project discharges into an oversized flood control channel erosion may not occur because the channel spreads flow over a large surface area, reducing boundary shear stresses. The applicant could demonstrate this by calculating the flows associated with the flow control range (0.2Q5 to Q10) and using a simple hydraulic model (Excel or 1D hydraulic model) to calculate the boundary shear stress in the

receiving channel. If some or all of the flow range is less than critical shear stress the applicant could seek a rise in the lower threshold to critical shear stress.

References

Hanson, G. J., Cook, K. R. Apparatus, test procedures, and analytical methods to measure soil erodibility *in situ*. Applied Engineering in Agriculture, 2004 (Vol. 20) (No. 4) 455-462

BROWN AND CALDWELL

Memorandum

9665 Chesapeake Drive, Suite 201
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Project Title: San Diego County Hydrograph Modification Plan

Project No: 133904

San Diego County Hydrograph Modification Plan

Subject: Using Continuous Simulation to Size Storm water Control Facilities

Date: April 30, 2008

To: Sara Agahi, San Diego County

From: Tony Dubin, Brown and Caldwell
Nancy Gardner, Brown and Caldwell

Brown and Caldwell prepared this memo to help civil engineers through the process of sizing storm water control facilities to meet San Diego County's Interim Hydromodification Criteria (IHC). Since the publication of the IHC this past January, the County has been engaged in outreach activities to explain the new storm water modeling methods required by the IHC and storm water facilities that could meet the IHC performance standard. In response to the outreach efforts, the County has received several questions and comments along a common theme:

1. How do we perform continuous hydrologic modeling analyses to size storm water control facilities?
2. What is the precise meaning of the peak flow and flow duration curve matching standard described in the IHC memo?

This document is not a complete "how-to manual" for conducting continuous hydrologic modeling to meet the County's IHC, but we hope it addresses the major technical concerns of the local engineering community.

Using Continuous Simulation Models to Size Storm Water Facilities

The IHC requires continuous simulation hydrologic modeling to adequately size storm water control facilities. This is a significant break with the common local practice of using event-based modeling to determine whether a storm water pond, swale or other device was properly sized. Event-based modeling computes storm water runoff rates and volumes generated by a synthetic rainfall event with a total depth that matches local records (e.g., rainfall depths shown in County isopluvial maps). By contrast, continuous modeling uses a long time series of actual recorded precipitation data as input a hydrologic model. The model in turn simulates hydrologic fluxes (e.g., surface runoff, groundwater recharge, evapotranspiration) for each model time step.

Continuous hydrologic models are usually run using one-hour or 15-minute time steps, depending on the type of precipitation data available and computational complexity of the model. Continuous models generate outputs for each model time step and most software packages allow the user to output a variety of different hydrologic flux terms. For example, a continuous simulation model setup with 25 years of hourly precipitation data will generate 25 years of hourly runoff estimates, which corresponds to runoff estimates for each of the 219,000 time steps (each date and hour) of the 25 year simulation period. While creating and running continuous simulation models involves more effort than running event-based models, the clear benefit of the continuous approach is that these models allow an engineer to estimate how often and for how long flows will exceed a particular threshold. Limiting how often and for how long geomorphically significant flows occur is at the heart of San Diego County's approach to hydrograph modification management.

Two common models were presented at a recent APWA workshop on HMP issues: HSPF and HEC-HMS. HSPF refers to the Hydrologic Simulation Program-FORTRAN and is distributed by the USEPA. HEC-HMS refers to the Hydrologic Modeling System (HMS) produced by the US Army Corps of Engineers Hydraulic Engineering Center (HEC). Engineers unfamiliar with these software packages should seek out training opportunities and online guidance. The USEPA conducts training workshops around the US to help teach engineers how to use HSPF. HEC-HMS training is provided through ASCE and third-party vendors.

The following list describes the major elements of developing a hydrologic model and using that model to size storm water facilities that meet the IHC.

1. Select an appropriate historical precipitation dataset for the analysis.
   a. The precipitation station should be located near the project site or at least receive similar rainfall intensities and volumes as the project site.
   b. The station should also have a minimum of 25-years of data recorded at hourly intervals or more frequently.
2. Develop a model to represent the pre-project conditions, including
   a. Land cover types
   b. Soil characteristics
   c. General drainage direction
3. Develop a model to represent the post-project conditions, including
   a. New land cover types – more impervious surfaces
   b. Soil characteristics
   c. Any modifications to the drainage layout
4. Examine the model results to determine how the proposed development affects storm water flows
   a. Compute peak flow recurrence statistics (described below)
   b. Compute flow duration series statistics (described below)
5. Iteratively size storm water control facilities until the post-project peak flows and durations meet the performance standard described below.

Understanding the Peak Flow and Flow Duration Performance Criteria

The IHC is based on a peak flow and flow duration performance standard. To compute the peak flow and flow duration statistics described in the standard, model users must have a method for evaluating long time series outputs (usually longer than the 65,000 rows available in MS Excel 2003 and earlier versions) and computing both peak flow frequency statistics and flow duration statistics.

We recommend computing **peak flow frequency statistics** by constructing a partial-duration series (rather than an "annual maximum" series). This involves examining the entire runoff time series generated by the model, dividing the runoff time series into a set of discrete unrelated events, determining the peak flow for each event, ranking the peak flows for all events and then computing the recurrence interval or plotting position for each storm event. To limit the number of discrete events to a manageable number, we usually only select events that are larger than a 3-month recurrence when generating the partial duration series. We consider flow events to be "separate" when flow rates drop below a threshold value for a period of at least 24 hours.

The exercise described above will generate a table of peak flows and corresponding recurrence intervals (i.e., frequency of occurrence for a particular flow). For continuous modeling and peak flow frequency statistics, it is important to remember that events refer to *flow events* and not precipitation events. Peak flow frequency statistics estimate how often flow rates will exceed a given threshold. For example, the 5-year flow event represents the flow rate that is equaled or exceeded an average of once per 5 years (and the storm generating this flow does not necessarily correspond to the 5-year precipitation event). Ranking the storm events generated by a continuous simulation and computing the recurrence interval of each storm will generate a table similar to Table 1 below.

Readers who are unfamiliar with how to compute the partial-duration series should consult reference books or online resources for additional information. For example, *Hydrology for Engineers*, by Linsley et all, 1982, discusses partial-duration series on pages 373-374 and computing recurrence intervals or plotting positions on page 359. *Handbook of Applied Hydrology*, by Chow, 1964, contains a detailed discussion of flow frequency analysis, including Annual Exceedance, Partial-Duration and Extreme Value series methods, in Chapter 8. The US Geological Survey (USGS) has several hydrologic study reports available online that use partial-duration series statistics (see http://water.usgs.gov/ and http://water.usgs.gov/osw/bulletin17b/AGU_Langbein_1949.pdf).

Table 1. Example Peak Flow Frequency Statistics

Recurrence Interval (years)	Peak Flow (cfs per acre)
58.5	0.73
21.9	0.69
13.5	0.53
9.8	0.53
7.6	0.51
6.3	0.51
5.3	0.50
4.6	0.50
4.1	0.49
3.7	0.48
3.3	0.48
3.0	0.46
2.8	0.45
2.6	0.45
2.4	0.45
2.3	0.45
2.1	0.44
2.0	0.42

Flow duration statistics are more straightforward to compute than peak flow frequency statistics. Flow duration statistics provide a simply summary of how often a particular flow rate is exceeded. To compute the flow duration series, rank the entire runoff time series output and divide the results into discrete bins. Then, compute how often the flow threshold dividing each bin is exceeded. For example, let's assume the results of a 35-year continuous simulation hydrologic model with hourly time steps show that flows leaving a project site exceeded 5 cfs an average of about once per year for 30 hours at a time. This corresponds to a total of

1050 hours of flows exceeding 5 cfs over 35 years. Another way to express this information is to say a flow rate of 5 cfs is exceeded 0.34 percent of the time. Computing the "exceedance percentage" for other flow rates will fill out the flow duration series. Table 2 lists an example flow duration series.

Table 2. Example Flow Duration Statistics

Flow (cfs per acre)	Percent of Time Flow Rate is Exceeded
0.02	0.67%
0.03	0.43%
0.04	0.34%
0.06	0.27%
0.07	0.21%
0.09	0.17%
0.10	0.15%
0.12	0.12%
0.13	0.11%
0.15	0.09%
0.16	0.08%
0.17	0.07%
0.19	0.06%
0.20	0.05%
0.22	0.05%
0.23	0.04%
0.25	0.04%
0.26	0.03%

The intention of the IHC performance standard is to limit the potential for new development to generate accelerated erosion of stream banks and stream bed material in the local watershed by matching the post-project hydrograph to the pre-project hydrograph for the range of flows that are likely to generate significant amounts of erosion within the creek. The IHC memo identified the geomorphically significant flow range as extending from two-tenths of the 5-year flow to the 10-year flow (0.2Q5 to Q10). The performance standard requires the following:

A. For flow rates from 20% of the pre-project 5-year runoff event (0.2Q5) to the pre-project 10-year runoff event (Q10), the post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10% over more than 10% of the length of the flow duration curve.

B. For flow rates from 0.2Q5 to Q5, the post-project peak flows shall not exceed pre-project peak flows. For flow rates from Q5 to Q10, post-project peak flows may exceed pre-project flows by up to 10% for a 1-year frequency interval. For example, post-project flows could exceed pre-project flows by up to 10% for the interval from Q9 to Q10 or from Q5.5 to Q6.5, but not from Q8 to Q10.

Determining When a Storm Water Control Facility Meets the IHC Performance Standard

The previous section discussed how to calculate peak flow frequency and flow duration statistics. By comparing the peak flow frequency and flow duration series for pre-project and post-project conditions, an engineer can determine whether a stormwater control facility would perform adequately or if its size should be increased or decreased. The easiest way to determine if a particular storm water facility meets the IHC performance standard is to plot peak flow frequency curves and flow duration curves for the pre-project and post-project conditions.

Figure 1 shows a **flow duration curve** for a hypothetical development. The three curves show what percentage of the time a range of flow rates are exceeded for three different conditions: pre-project, post-project and post-project with storm water mitigation. Under pre-project conditions the minimum geomorphically significant flow rate (assumed to be 0.2Q5) is 0.10 cfs and flows would equal or exceed this value about 0.14% of the time (about 12 hours per year). For post-project conditions, this flow rate would occur more often – about 0.38% of the time (about 33 hours per year). This increase in the duration of the geomorphically significant flow after development illustrates why duration control is closely linked to protecting creeks from accelerated erosion. Higher flows that last for longer durations provide the energy necessary to increase the amount of erosion in local creeks. The post-project mitigated condition would include stormwater controls designed to limit the duration of geomorphically significant flows. Figure 1 shows that flows exceed 0.10 cfs only 0.08% of the time, which is less than pre-project conditions. This means the stormwater control mitigations would counteract the effects of the increased pavement associated with development projects.

An engineer can easily interpret the flow duration plots to determine whether a stormwater control facility would meet the IHC. Looking at the flow range between 0.2Q5 and Q10, the post-project mitigated curve should plot on or to the left of the pre-project curve. If the post-project curve plots to the left of the pre-project curve, this means a particular flow would occur for shorter durations due to storm water controls. Minor deviations where the post-project durations exceed the pre-project durations are allowed over a short portion of the flow range as described in IHC item A above.

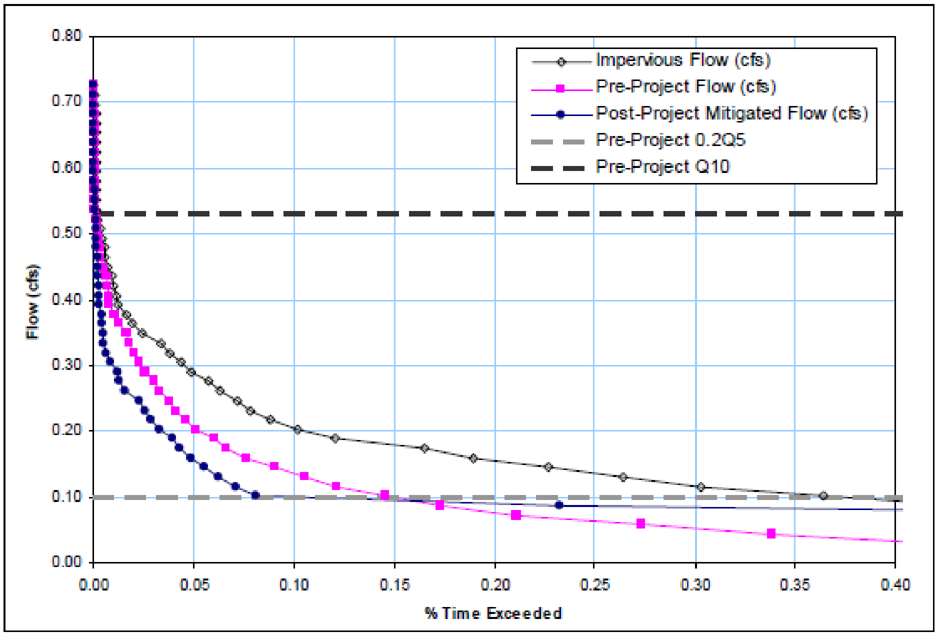

Figure 1. Flow Duration Series Statistics for a Hypothetical Development Scenario

Figure 2 shows a **peak flow frequency curve** for pre-project, post-project and post-project with storm water mitigation scenarios. The curves indicate how often a particular flow rate would be equaled or exceeded. For example, the pre-project 5 year flow rate would be 0.5 cfs per acre. This means under pre-project conditions, a flow rate of 0.5 cfs per acre would be equaled or exceeded an average of once per 5 years. For developed conditions, this 0.5 cfs per acre peak flow rate occur more often – about once per 1.5 years or, expressed another way, more than 3 times as often. The developed 5 year flow rate would increase by 30 percent over the pre-project condition, from 0.5 cfs per acre to about 0.65 cfs per acre.

Storm water control facilities should reduce peak flows from the site to levels less than or equivalent to the pre-project conditions. To determine whether a storm water facility provides sufficient protection, examine the peak flow frequency curves to see if the post-project mitigated peak flows are lower than pre-project peak flows of the same recurrence interval. The post-project mitigated scenario curve should plot below the pre-project curve for recurrence intervals between 0.2Q5 and Q10 to meet the IHC performance standard, with the possible exception of the small, allowable deviations described above in IHC item B.

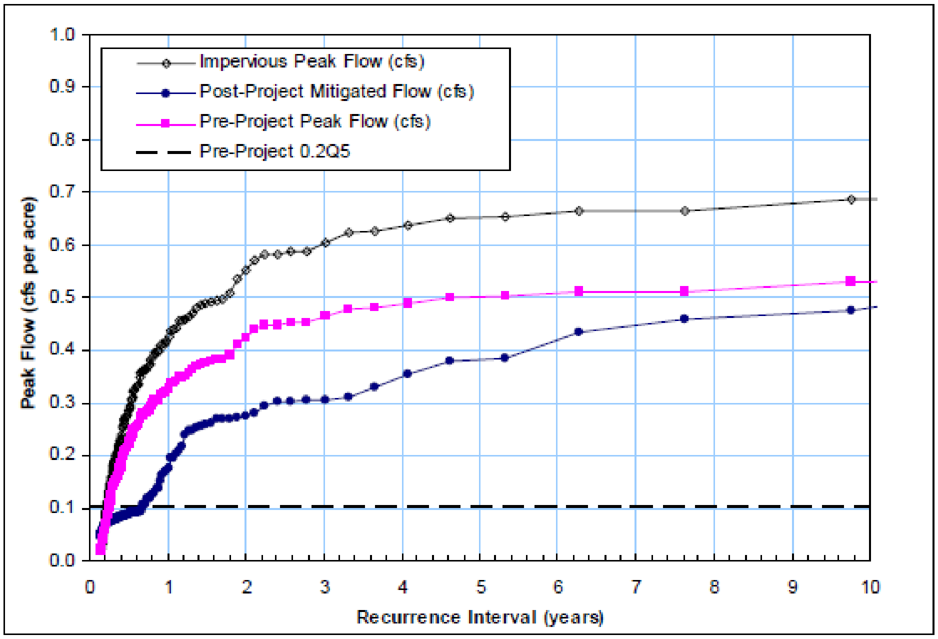

Figure 2. Peak Flow Frequency Statistics for a Hypothetical Development Scenario

References

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